# Recent Science of the ARM Vertical Velocity Focus Group

*Retrieving cloud-scale vertical velocity from active remote sensors*

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Presented by Stephen A. Klein (PCMDI/LLNL)

ARM
Atmospheric Radiation Measurement

The Fall 2009 Joint Meeting of the ARM Aerosol and Cloud Modeling Working Groups
Boulder, Colorado
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# Outline

- Boundary layer vertical velocities *(Chandra and Kollias 2009, Hogan et al. 2009)*
- Shallow cumulus vertical velocities *(Kollias and Albrecht 2009)*
- Deep convection vertical velocities *(Kollias and Giagrande, in preparation)*
- I won't cover:
  - Jay Mace's vertical velocities in cirrus *(Deng and Mace JGR 2006, 2008)*
  - Matt Shupe's vertical velocities in Arctic mixed-phase stratus *(Shupe et al. JAS 2008)*

# Boundary Layer Vertical Velocities

- Vertically pointing (Doppler) MilliMeter Wavelength Cloud Radars (MMCR) measure the vertical velocity of the scatterer
- In the case of the clear atmospheric convective boundary layer, the scatterers are insects (if present) primarily, and aerosols and other matter secondarily
- You may choose to assume that the velocity of the scatterer is the air vertical motion (although insects have their own momentum)

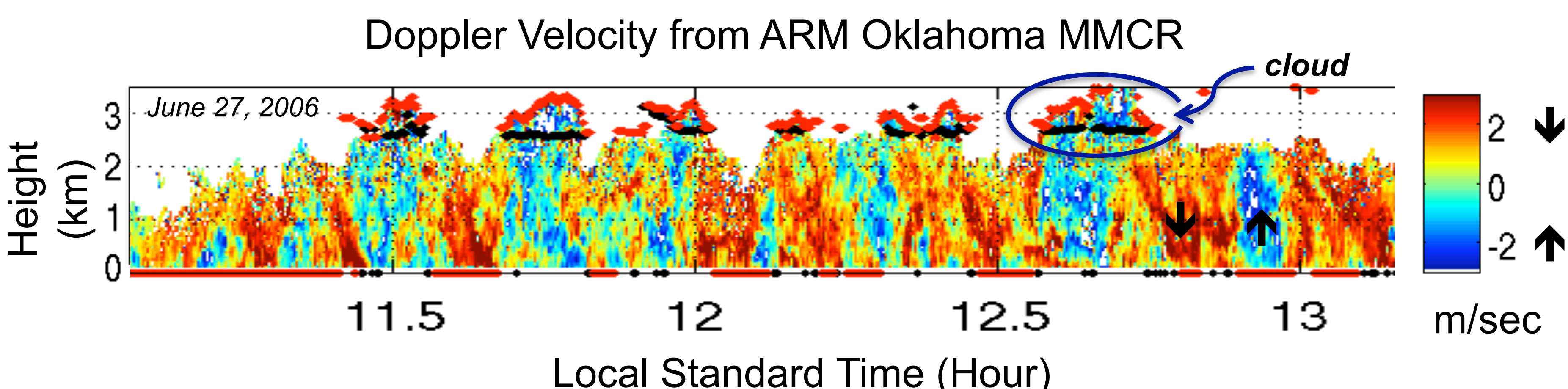
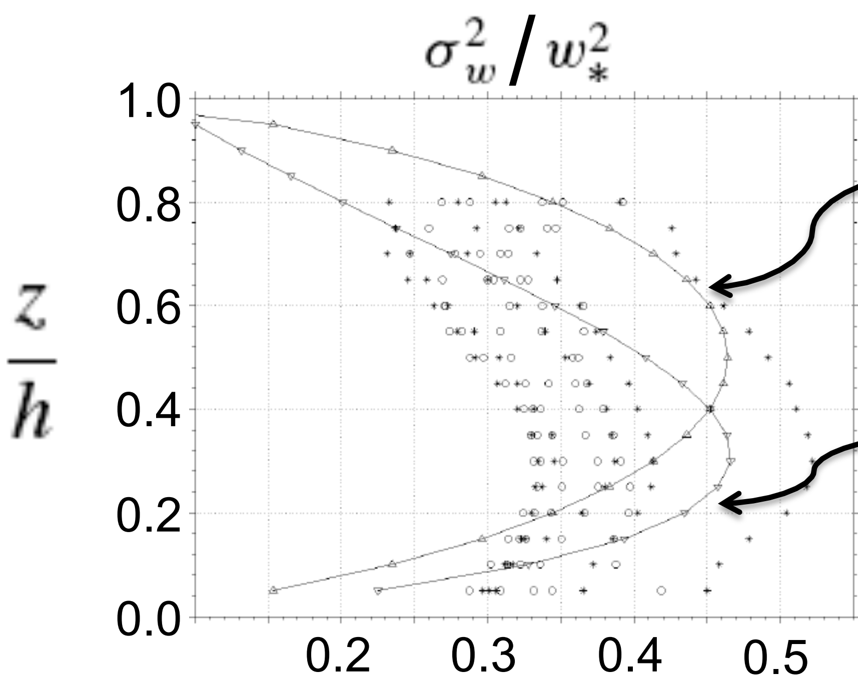



*Figure courtesy of Arunchandra Chandra (McGill U.)*

# Boundary Layer Vertical Velocities

*Pavlos Kollias, Arunchandra Chandra, and Scott Giagrande (McGill U.), Steve Klein (LLNL)*

- Using over 300 days of clear convective boundary layers are the ARM Oklahoma site, one can examine the vertical profile of vertical velocity variance and skewness
- Radar observations are broadly consistent with parameterizations based on old aircraft studies




$$\frac{\sigma_w^2}{w_*^2} = 1.17\left[\frac{z}{h}\left(1-\frac{z}{h}\right)\right]^{2/3}$$

*Sorbjan (1989)*

$$\frac{\sigma_w^2}{w_*^2} = 1.8\left(\frac{z}{h}\right)^{2/3}\left(1-0.8\frac{z}{h}\right)^2$$

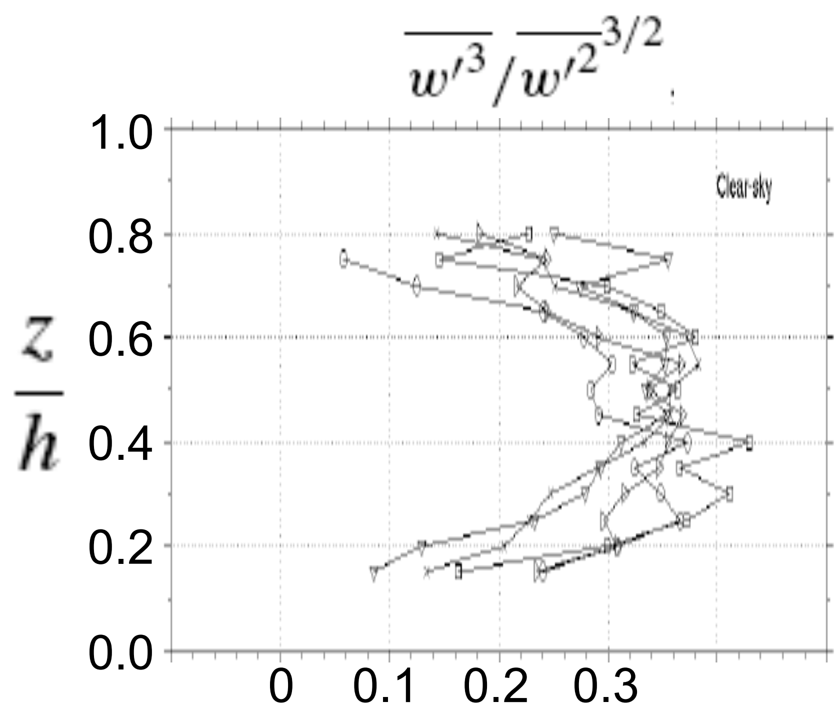
*Lenschow et al. (JAS 1980)*

*Chandra et al. (J. Clim. 2009, submitted)*

# Boundary Layer Vertical Velocities

*Pavlos Kollias, Arunchandra Chandra, and Scott Giagrande (McGill U.), Steve Klein (LLNL)*

- Convective boundary layers have positive skewness (as expected) due to heating from below
- Chandra et al. (2009) also compute convective mass-fluxes and show that over 80% majority of the mass-flux transport  is contributed by coherent vertical structures
- The observations could be used to assess eddy-diffusive mass-flux boundary layer parameterizations *(Siebesma et al. JAS 2007)*

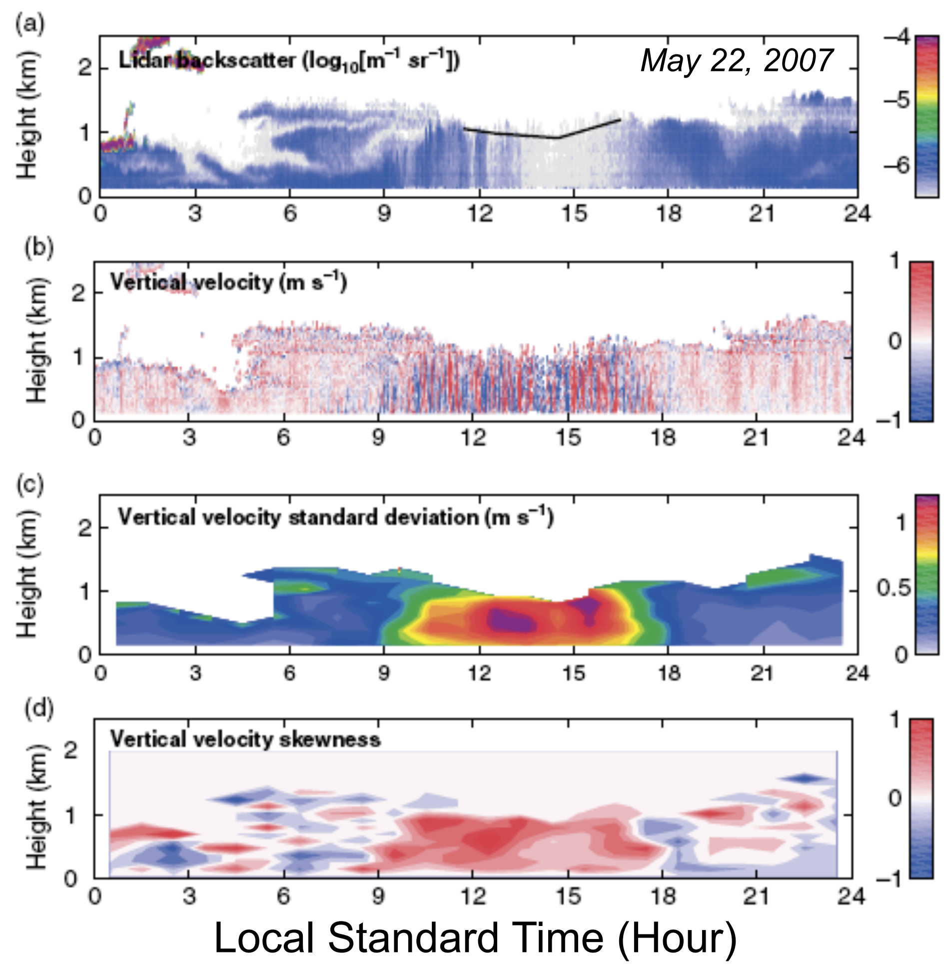



*Chandra et al. (J. Clim. 2009, submitted)*

# Boundary Layer Vertical Velocities

*Robin Hogan (U. Reading)*

- If you don't like insects, you can use a doppler lidar, which by using a wavelength in the near infrared ($\lambda$= 1.5 $\mu$m) is more sensitive to the smaller particles such as aerosols, to tell you about the vertical velocity in the clear-convective boundary layer
- ARM is getting doppler lidars with ARRA funds

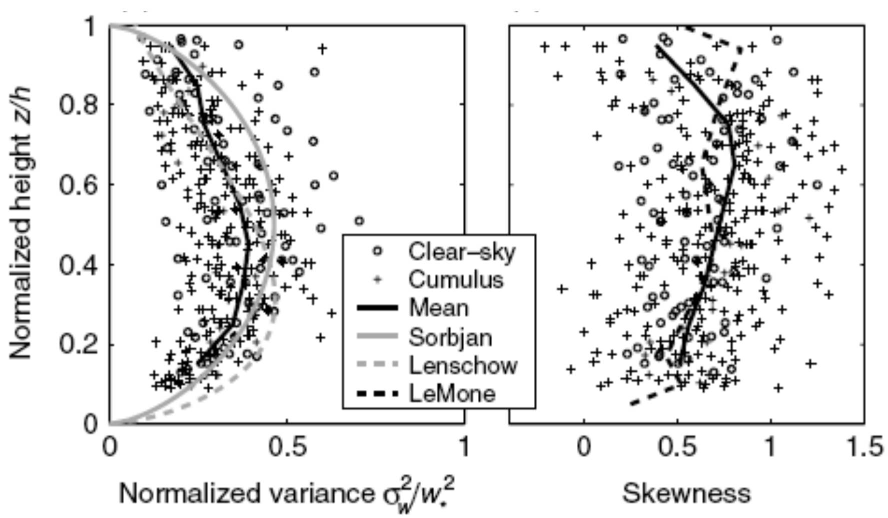



*Hogan et al. (Quart. J. Roy. Met. 2009)*

# Boundary Layer Vertical Velocities

*Robin Hogan (U. Reading)*

- These doppler lidar observations confirm the millimeter wavelength cloud radar results for variance and skewness
- For nocturnal boundary layer clouds, negative skewness is found beneath cloud base → this is characteristic of turbulence driven from cloud-top radiative cooling
- Lidars are not as helpful for boundary layer clouds because they can't penetrate beyond an optical depth of 3




*Hogan et al. (Quart. J. Roy. Met. 2009)*

# Shallow Cumulus Vertical Velocities

*Pavlos Kollias (McGill U.) and Bruce Albrecht (U. Miami)*

- For non-precipitating shallow cumulus clouds, the scatterer targets of MMCR radiation are liquid cloud droplets
- Because cloud droplets are small, it is a good assumption that the vertical velocity of the droplet is the vertical air motion
- Last year, Yunyan Zhang and I (LLNL) showed you statistics of the vertical velocity of shallow cumulus over Oklahoma. These statistics included the updraft and downdraft areas, velocities and mass-fluxes.
- Today I will show you Pavlos's analysis of the diurnal cycle of shallow cumulus clouds over Nauru. Diurnal cycle composites of 10 years of Nauru MMCR data are segregated by the low-level wind direction to separate clouds that are contaminated by the island effect from oceanic cumulus

# Shallow Cumulus Vertical Velocities

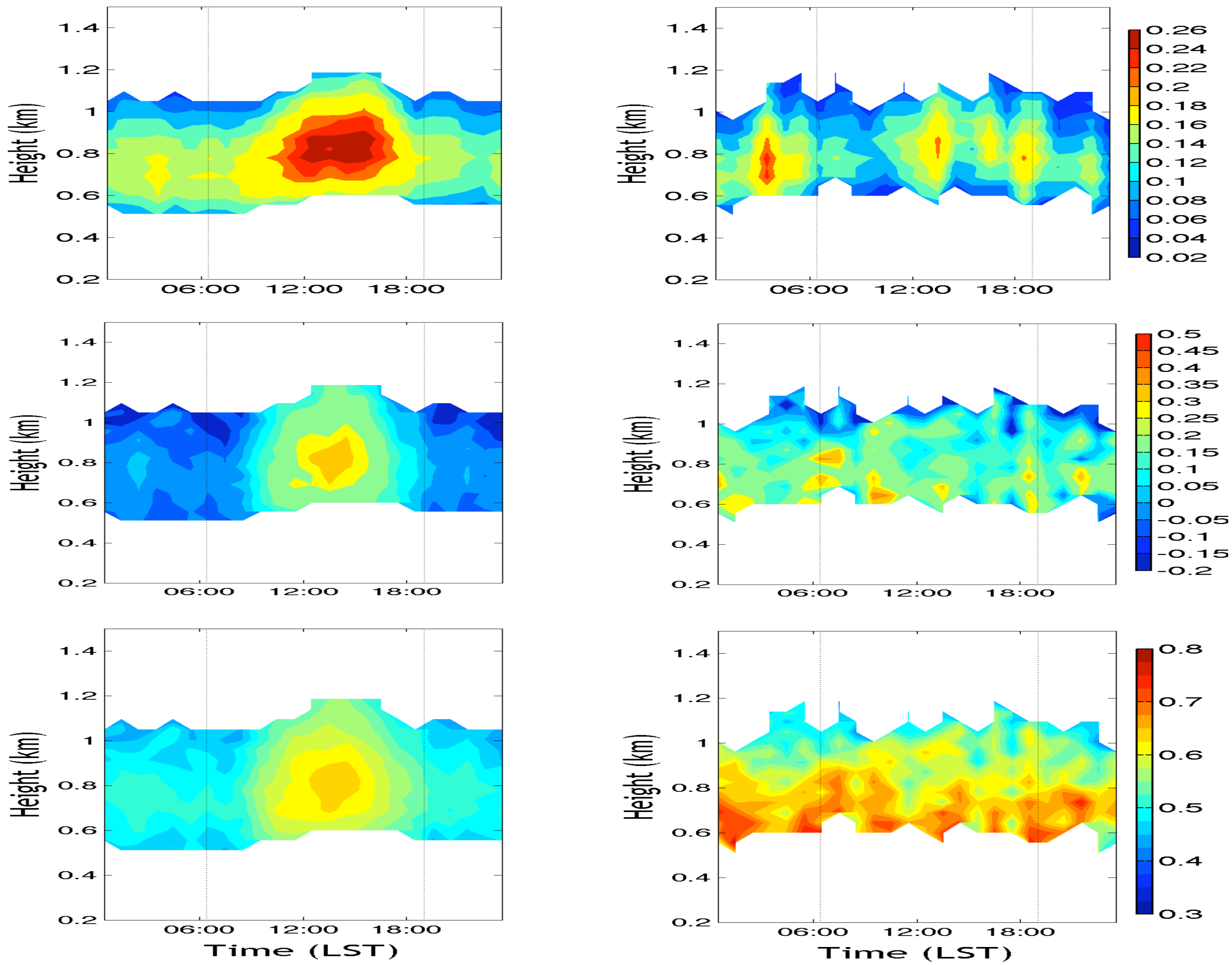
*Pavlos Kollias (McGill U.) and Bruce Albrecht (U. Miami)*

Easterlies (Island Effect) | Westerlies (Ocean Clouds)

Cloud Fraction

Vertical Motion

Updraft Fraction



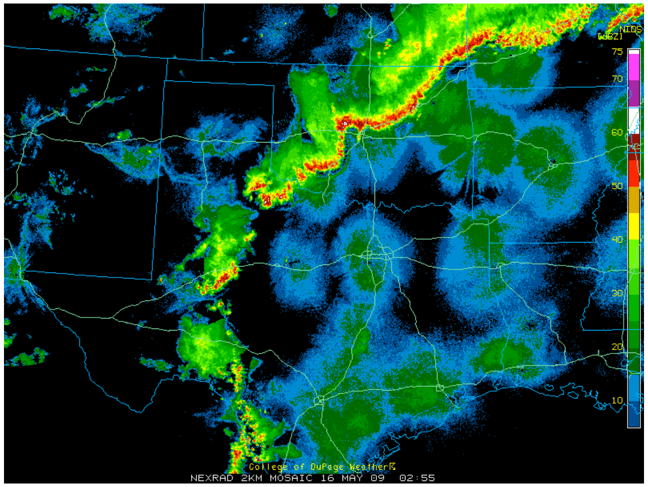

m $sec^{-1}$

# Deep Convection Vertical Velocities

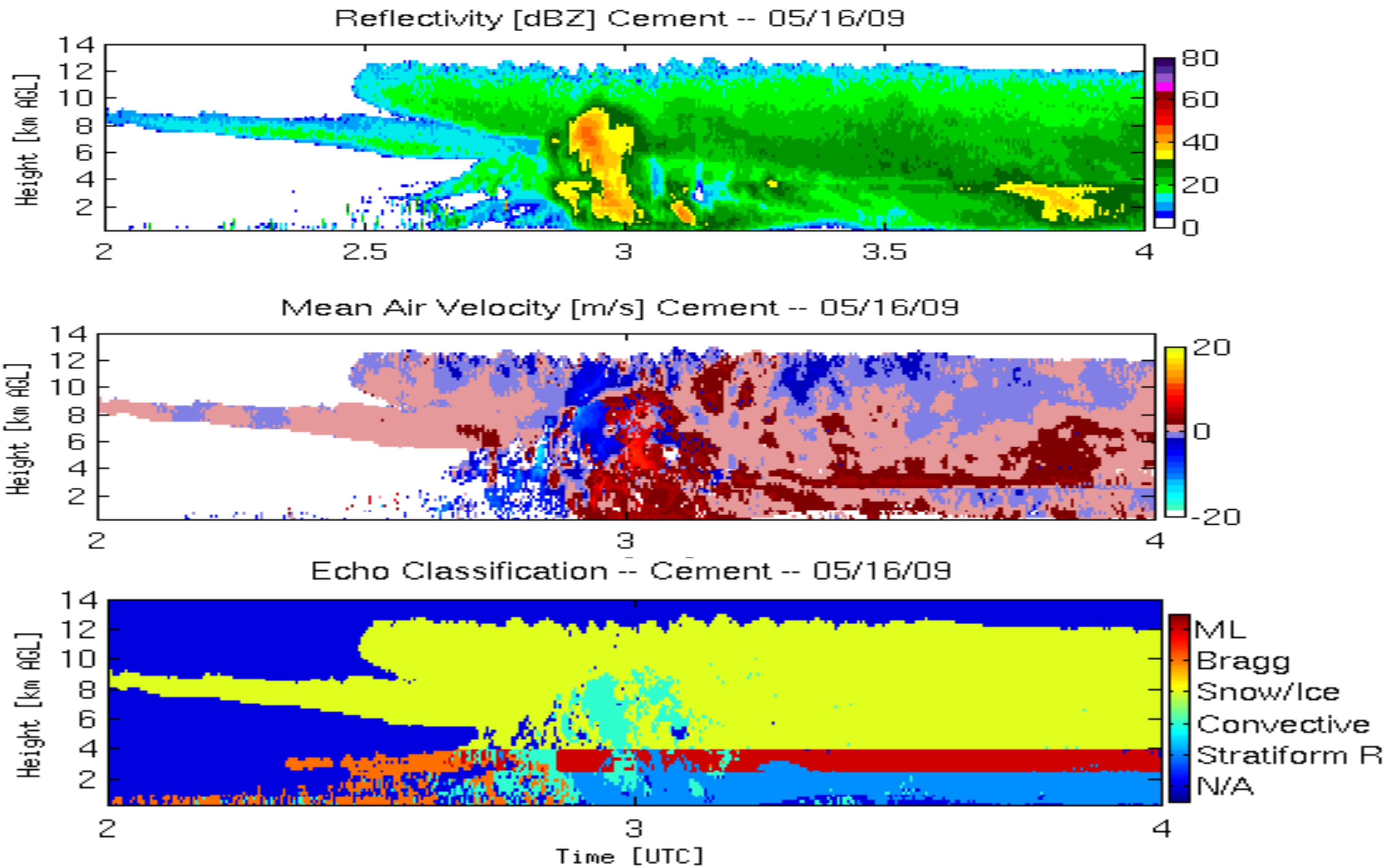
*Pavlos Kollias and Scott Giagrande (McGill U.)*

- Two 915-MHz wind profilers have been reconfigured with new sampling strategy to observe deep precipitation
- Preliminary algorithms have been developed for hydrometeor identification and vertical velocity retrievals (accounting for hydrometeor fall speeds)

Radar Mosaic, May 16, 2009




- Use of collocated disdrometers for drop-size distributions measurements, hydrometeor identification verification and radar calibration
- Vertical resolution: 200 meters, Temporal resolution: 10 seconds, Estimated velocity accuracy: 1 m $sec^{-1}$




http://meteo.mcgill.ca/ARM_Profiler/doku.php

# Final Remarks

- The science of cloud-scale vertical velocities retrievals from ground-based remote sensors is rapidly evolving
- New possibilities for modelers and observationalists to analyze multi-year records of cloud-scale vertical motions in order to:
  - Improve the understanding of the connection between cloud properties and small-scale cloud dynamics
  - Provide observational targets for Large-eddy simulations and aspects of large-scale model parameterizations